

1 PASSIVE RFID TRANSPONDER/MACHINE-MOUNTED ANTENNA AND
2 READER SYSTEM AND METHOD FOR HIDDEN OBSTACLE DETECTION AND
3 AVOIDANCE

4 This nonprovisional utility patent application claims the benefit of one or more
5 prior filed copending nonprovisional applications. The present application is a
6 Continuation of application 09/927,074, filed on August 9, 2001, which is incorporated
7 herein by reference in its entirety.

8 Background of the Invention

9 (1) Field of the Invention

10 The present invention relates generally to transponder/reader systems for the
11 avoidance of hidden, transponder-tagged objects and, more particularly, to a RFID
12 transponder/machine-mounted reader system for the detection and avoidance of hidden
13 utility fixtures during mowing and clearing operations using heavy machinery and for the
14 storage and transmission of information related to the transponder-tagged object.

15 (2) Description of the Prior Art

16 Public utilities such as electric power, gas lines, telephone cables, etc. crisscross
17 the landscape running through remote and often poorly accessible right-of-ways.
18 Periodically, these right-of-ways must be mowed and cleared of tall, dense vegetation,
19 including sapling trees. While the large objects such as the main power line towers are
20 easily avoided, the right-of-way usually contains much smaller objects such as telephone
21 pedestals. It is difficult and impractical to manually find and mark every pedestal each
22 time the right-of-way is cleared. When a telephone junction pedestal is accidentally

1 destroyed by the mowing equipment, the repairs are expensive and time-consuming to the
2 utility company and at the very least an irritation to the service users. In some instances
3 where health monitoring or security systems are using the circuits, the outages resulting
4 from such severe damage can be much more serious. Based on actual experience, only
5 about 5% of the telephone pedestals within a power right-of-way are marked accurately
6 before clearing begins. Thus, a need exists for an effective system for preventing
7 accidental damage to the communications junctions and other utility fixtures at a very low
8 cost.

9 Summary of the Invention

10 The present invention is directed to a system of transponder tags/vehicle-mounted
11 reader for hidden obstacle detection and avoidance.

12 Preferably, the present invention uses passive RFID transponder tags with a
13 vehicle-mounted reader for the detection and avoidance of hidden obstacles.

14 The present invention is further direct to a system of object identification to
15 provide detailed information pertaining to the tagged object.

16 The present invention is further directed to a method for the detection and
17 avoidance of hidden obstacles.

18 Thus, the present invention provides a system of transponder tags/vehicle-
19 mounted reader for hidden obstacle detection and avoidance.

1 These and other aspects of the present invention will become apparent to those
2 skilled in the art after a reading of the following description of the preferred embodiment
3 when considered with the drawings.

4 Brief Description of the Drawings

5 Figure 1 is a diagrammatic view of a transponder/reader system for the detection
6 of hidden objects constructed according to the present invention.

7 Figure 2 is a detailed view of the user interface according to an embodiment of the
8 present invention.

9 Detailed Description of the Preferred Embodiments

10 In the following description, like reference characters designate like or
11 corresponding parts throughout the several views. Also in the following description, it is
12 to be understood that such terms as "forward," "rearward," "front," "back," "right,"
13 "left," "upwardly," "downwardly," and the like are words of convenience and are not to
14 be construed as limiting terms.

15 Referring now to the drawings in general, the illustrations are for the purpose of
16 describing a preferred embodiment of the invention and are not intended to limit the
17 invention thereto. As best seen in Figure 1, the detector system, generally described as
18 10, includes a transponder 20, in discontinuous radio frequency communication 21 with a
19 machine-mounted RF transponder detection system, generally described as 30. The
20 machine-mounted RF transponder detection system is composed of an RF interrogator 40
21 connected to at least one antenna 50 and the control head 60.

1 More particularly, the transponder 20 is preferably a passive Radio Frequency
2 Identification (RFID) transponder. A passive transponder requires no battery and
3 contains integrated non-volatile memory that allows data to be written to and read from
4 individual tags. The transponder tag can be programmed with any type of data desired
5 within the size constraint of the memory. This programming may be done in the field at
6 installation or prior to installation. However, it is not necessary to have any user
7 programming performed for the system to work, as each transponder is factory
8 programmed with a unique identification (ID) number, which is all that is needed for
9 positive detection and identification. Thus, the transponder may be of a type that only
10 transmits a signal to indicate presence, or of a type that can output other information, such
11 as a unique identifier, specific location, description of the tagged object, maintenance
12 dates, test results, and the like. For example, the unique identifier may be the
13 Transmission Electric Facilities Information System (TEFIS) identifier. The location
14 information may be the location based on the global positioning system (GPS) or relative
15 location, such as the relationship of the particular RFID to other RFID transponders or to
16 local buried utilities. The description of the tagged object may include the nature of the
17 equipment tagged, the responsible utility service provider, and other information.

18 In the preferred embodiment or best mode, the type of data stored in the tag is
19 virtually unlimited. The current technology for the 915MHz tags allows for a total
20 storage capacity of 1024 bits of which 880 are available for use in the application. That
21 space would hold approximately 145 ASCII characters uncompressed. Numeric data is
22 capable of being stored in binary form. It is expected that the memory capacity will
23 increase as the technology matures; as such the scope of the present invention is intended

1 to include such memory capacity increases. The remaining memory in this embodiment,
2 144 bits, is reserved for tag identification and format information. A unique 64-bit ID
3 number is assigned to each tag made, another 32 bits are reserved for a manufacturer/tag
4 type code and the last 48 bits are reserved for tag memory layout which can be different
5 for each type of application. The following list is representative of the type of data that
6 can be useful in this application. The formatting and memory allotment following some
7 of the types of data are to demonstrate how the available 880 bits could be used.
8 Examples of data that can be stored include: Object Types (8-bit reference code supports
9 256 types), Telephone Pedestal, Fiber Optic Junction, Water Hydrant, Gas Valve, Power
10 Transformer, Guy Wire, Cable anchors, Power Pole, Telephone Pole, Boundary Marker,
11 Survey Control Point (SCP), Fence, River/Stream, Metal Tower, Road/Highway, Owner
12 (136 bits), Utility Name (96 bits), Emergency Phone Number (40 bits), TEFIS Number
13 (32 bits), Location (degrees - 48 bits), Latitude (24 bits), Longitude (24 bits), Install Date
14 (16 bits), Absolute days since Jan 1, 1900, Last Service Date (16 bits), Absolute days
15 since Jan 1, 1900, Local References Count (4 bits), References variable list of up to 15
16 nearby reference points, Local Reference (40 bits), Distance to object (16 bits -
17 centimeters (655 meters max), Direction to object- 16 bits - degrees, Object type code - 8
18 bits. Any additional data could be easily stored in a database indexed to the tag ID
19 number - each of which is unique in the world.

20 The transponder's function is to alert the machine operator to the presence of a
21 hidden object. To perform this task, the transponder needs to provide the operator with
22 an alert signal approximately two seconds prior to the moving machine physically
23 contacting the hidden object. Thus, the time between signal reception by the transponder

1 and alerting of the operator, called the lag time, is preferably as short as possible, or at
2 least provides for a reasonable response time from the operator.

3 The RF transponder detection system interrogates the surrounding area for tags a
4 multiplicity of times per predetermined period; for the present invention embodiment, the
5 surrounding area or transponder vicinity is interrogated approximately 200 times per
6 second. Tests show apparent system lag time to be very small in terms of human reaction
7 time and closure rates in the range of 5 ft/sec, which provide for a reasonable response
8 time by the operator and are considered typical for this application. In the tests, the alert
9 for a given configuration occurred at the same physical point for a variety of closing
10 velocities. The majority of the response time is needed for the operator to respond to a
11 visual cue and bring the machine to a stop. On average, the equipment needs to reliably
12 record a target at a range of 10 to 12 feet in moderate undergrowth. The testing that was
13 done showed the equipment constructed and configured according to the present
14 invention was capable of meeting this performance standard.

15 This lag time is a function of several factors, including at least the detectable
16 signal range of the system, the reaction time of the transponder, the physical environment,
17 and the velocity of the machine. Therefore, the transponder according to the present
18 invention preferably has a sufficiently short reaction time such that it can alert a vehicle
19 moving at the highest rated velocity in the most undesirable environmental conditions in
20 sufficient time to avoid a collision of the machine and the transponder-tagged object.

1 Examining the sequence of events in terms of distance when approaching a
2 tagged, hidden obstacle using typical operating parameters illustrates the detection range
3 requirements.

4 Assuming the case of moderate to heavy cover, which results in the poorest
5 visibility conditions, the maximum machine speed suggested is of 2.5 mph, equaling
6 approximately 3.7 ft/sec. The operator reaction time is approximately 0.5 seconds,
7 equaling approximately 1.8 ft. The worst case for the machine stopping distance is 5 ft;
8 in practice the machine can stop almost instantly. The antenna offset behind the leading
9 edge of the cutter head is approximately 3 ft. Therefore, the minimum detection range
10 from the front of the machine required is approximately $1.8 + 5.0 + 3.0 = 9.8$ ft.

11 Alternatively, if the detection system is designed to alert at least two seconds
12 before contacting the object, and the operator requires the entire two seconds to stop the
13 machine, the following results are obtained:

14 A speed of 3.7 ft/sec produces a minimum distance to stop of $3.7 \text{ ft/sec} * 2 \text{ sec} =$
15 7.3 ft. The antenna offset behind leading edge of the cutter head is approximately 3 ft.

16 Therefore, the detection range in front of the leading edge of the cutter head must
17 equal at least $7.3 + 3.0 = 10.3$ ft.

18 The estimates agree well with each other and are reasonable approximations.
19 Hence the minimum detection range requirement for the system is 10 to 12 feet.

20 Conditions that may adversely affect the detection range of the system include the
21 following: signal polarization, vegetation density, water, type of plant or vegetation,
22 contact surfaces, and shielding. Preferably, the following considerations are

1 recommended to ensure proper functioning of the system according to the present
2 invention.

3 Polarization - The tags and reader antenna should be oriented correctly. Also,
4 other antenna techniques such as circular polarization could be employed if required.

5 Vegetation Density - The more scattering elements between the tag and the reader
6 the more the signal will be attenuated.

7 Water - The wetter the scattering elements are, the more the signal will be
8 attenuated; however, comparisons between dry and wet brush did not show a significant
9 loss of performance.

10 Type of Plant - The type of plant and the size of the leaves made noticeable
11 differences in the detection range.

12 Contact surfaces - The tags cannot be placed directly against metal.

13 Shielding - Metal structures will shield the tags and impair detection. The tags
14 must be located at the apex of any completely metal object to achieve omnidirectional
15 detection.

16 Other characteristics of the transponder that may affect the response time will
17 include the minimum input power level for activation, the inherent delay of the
18 transponder circuitry, the alert signal power level, and the effect of temperature, humidity,
19 RF interference and other environmental conditions on the transponder. Characteristics
20 of the machine-mounted components of the system that affect the response time include
21 the interrogatory signal power level of the RF interrogator 40, the alert signal power level

1 of the transponder, the detection threshold of the RF interrogator, and the gain of the
2 antenna.

3 Because the transponder is preferably a passive transponder, the lower the input
4 energy required by it to generate an alert signal, the farther the detection range it will
5 have. Therefore, it is desirable that the transponder operate at frequencies that are less
6 susceptible to environmental interference and thus require less power to achieve a given
7 range. This frequency range is preferably between about 13.5 MHz and 2.45 GHz, more
8 preferably about 915 Mhz. The FCC has set aside a band of frequencies from 902-
9 928MHz for various purposes. The 915MHz system according to the present invention
10 falls into the spread-spectrum application defined in Part 15 of the FCC regulations.

11 Lower frequencies such as 13.5MHz are better at penetrating heavy foliage given
12 all other parameters of the system are held constant. However, "equivalent" antennas for
13 that frequency would have physical dimensions measuring several feet as opposed several
14 inches making the overall system much less practical. Thus, higher UHF frequencies
15 allow the desired smaller antenna geometries to be much more efficient than they would
16 be at a lower RFID frequency like 13.5MHz and offer a good compromise over the
17 microwave RFID tags operating at 2.45Ghz which have very poor penetration
18 characteristics. Systems currently on the market operating in these other two bands
19 typically advertise read ranges in centimeters. Thus, the performance of the tags and the
20 reader at approximately 915 MHz allows for a smaller antenna geometry and offsets the
21 relative reduction in penetrating ability.

1 The RF interrogator is mounted on the machine and generates an interrogatory
2 signal that is transmitted via the at least one antenna in the direction of travel. This signal
3 activates the transponder, and therefore is of appropriate frequency and power to activate
4 a transponder within the desired detection range. The appropriate frequency is preferably
5 between about 13.5 MHz and 2.45 GHz, more preferably about 915 Mhz.

6 Among the hardware available in the RFID industry today the most appropriate
7 technologies for this application use 915MHz as the operating frequency.

8 The at least one antenna can be a single antenna or multiple antennae. In the case
9 of use of a single antenna, it can be an omnidirectional antenna, unidirectional antenna, or
10 a directional antenna, such as a dipole antenna or yagi antenna, for increased
11 directionality and range.

12 Multiple antennae can be used to increase the directionality and/or range of the
13 system. For example, a phased antenna array can be used. These directional and/or
14 ranging antennae can enhance the ability of the operator to avoid hidden utility objects.

15 An alert signal coming from the transponder is received by the antenna, routed
16 through the RF interrogator, and then transmitted to the control head. In the control head,
17 generally described as 60 in Figure 2, the signal is received by a microprocessor (not
18 shown) that processes the signal and generates the appropriate output to the user interface
19 62. The outputs generated may include a sensory alarm to alert the user to the presence of
20 a transponder within the detectable range of the system. The sensory alarms may be
21 visual, auditory, or any other appropriate sensory alarm, and combinations thereof. For
22 example, in situations where there is a high level of background noise, such as mowing

1 high brush with a tractor-mounted mower, an audible alarm 64 alone may be insufficient
2 to ensure alerting of the operator, and therefore other alarms, such as a flashing red light
3 66, may be installed in the user interface. The outputs may further include the RFID
4 encoded data previously described, such as unique identifier and/or TEFIS number,
5 specific and/or relative location, description of the tagged object, and the like, displayed
6 in an LCD or similar display 68. These outputs can be generated by information
7 transmitted from the transponder, or can be information that is stored in the control head,
8 and pre-linked to the unique identifier transmitted by the transponder. In systems where
9 the transponder transmits the specific location of the transponder, and this location can be
10 linked to a TEFIS object, no reprogramming of the transponder is necessary prior to
11 affixing the transponder to a hidden object. Information about TEFIS object most closely
12 associated geographically with the GPS location of the transponder will be displayed on
13 the control head when the transponder alert signal is received. In cases where the GPS
14 location of the transponder can be either transmitted by the transponder or calculated by
15 the microprocessor as described, and the machine is equipped with a GPS system, the
16 direction and distance of the transponder from the machine can be determined and
17 displayed on the display 68.

18 Additionally, the control head may be designed to enable simultaneous detection
19 of multiple transponders. In these cases, the control head would be designed to provide
20 an indication of how many separate tags were detected so that the operator would know
21 how many objects needed to be located and avoided. In systems using multiple antennae,
22 the direction of the transponders in relation to the machine can be more accurately
23 determined. For example, multiple, divergent yagi antennae can be arrayed to allow the

1 differentiation of the alert signal into sectors; for example, into three sectors such as dead
2 ahead, proximal left side, and proximal right side. This directional information can then
3 be displayed via the display 68 or via other appropriate means.

4 The control head also may include basic functions and indicators such as a power-
5 on indicator 70, an power switch 72, a test switch 74 to allow the operator to perform a
6 system confidence test, and a reset switch 76 that allows the operator to clear alerts
7 manually.

8 In a preferred embodiment according to the present invention, the system has a
9 usable read-range of approximately 15 ft to provide a two to three second warning to the
10 operator. The current technology that best suits the needs of this system are the IntelliTag
11 products from Intermec, which operate on or about the 915 Mhz frequency. In this
12 embodiment, the interrogator and antenna configuration transmit proprietary patterns of
13 RF energy designed to excite a passive tuned transponder circuit contained in packaged
14 tags attached to an object or alternately integral to the object casing. The placement of
15 the antenna or antennae is such that the radiation pattern extends forward of the tractor or
16 other equipment such that a tagged object would be detected as the machine moved
17 toward it and an appropriate alert would be given to the equipment operator warning
18 him/her of the objects close proximity, thus allowing time to stop the machine before the
19 objects is contacted physically. The transmitter is capable of operating continuously as
20 the mowing operation is carried out. Detection and alerts are all handled automatically.
21 Once a tagged object is detected it can be located and cleared since its approximate
22 location is now known, even though it was previously hidden either partially or

1 completely. Once the object has been visually located and can be avoided the operator
2 resets the alert, thus turning off the lamp and tone. The system is capable of ignoring
3 replies from the alerting tag until the replies stop as a result of the machine moving past
4 the object or turning away from it.

5 The RF transponder detection system can also be connected via wireless
6 technologies to larger or different databases in a remote location, e.g. an office, far from
7 the immediate area in order to provide additional information to the operator in the field.

8 A method for detecting and avoiding hidden utility objects includes tagging utility
9 objects with preprogrammed passive RFID transponders. The transponders may be
10 programmed during manufacturing or at later times, including up to installation. These
11 RFID may be preprogrammed with a simple presence signal or with more detailed
12 information. After the utility objects have been tagged, the vehicle operator can
13 commence operation with a vehicle fitted with the RF transponder detection system. The
14 vehicle operator powers on the RF transponder detection system and commences
15 operation of the vehicle. When a tuned transponder comes in the detection range of the
16 detection system, the RF transponder detection system alerts the machine operator to the
17 presence of the tuned transponder. The machine operators stops or slows the forward
18 progress of the machine and attempts to locate the tagged utility object. If the object is
19 not readily located, the operator stops the forward progress of the machine until the object
20 is located, based upon the system information indicating the location of an object within a
21 predetermined distance or area. Upon location of the object, the operator either stops the
22 forward progress of the machine, dismounts, and manually clears the object, or continues

1 the forward progress of the machine and avoids the object. Upon locating the object or
2 stopping the forward motion of the machine, the operator can reset the alert signal,
3 stopping the alert for the immediately detected object.

4 Certain modifications and improvements will occur to those skilled in the art upon
5 a reading of the foregoing description. By way of example, the user interface can be
6 expanded to show area maps based on a database of known tag locations. The map is
7 capable of automatically reregistering itself each time a known tag is encountered.
8 Another example is the connection of the reader via wireless technologies to larger or
9 different databases in an office far from the immediate area in order to provide additional
10 information to the reader in the field. Also, the system can be connected to the machine
11 and programmed to stop the machine automatically in case of emergency; for example, if
12 the machine is continuing to approach a detected RFID after sufficient warning has been
13 given to the operator. Another example is allowing phone lines or other power lines in a
14 pedestal to power an active tag, thus providing extended read ranges. Integrating the
15 system with GPS or DGPS for automatic initialization of newly installed tags is an
16 improvement that can facilitate installation. Another example is integration of the tag
17 into the body of the telephone pedestal itself, thereby preventing theft and vandalism.

18 All modifications and improvements have been deleted herein for the sake of
19 conciseness and readability but are properly within the scope of the following claims.

20